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Integration anxiety: The cognitive isolation of climate change

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ABSTRACT

Experts recommend that decision-makers in climate-vulnerable sectors integrate, or 'mainstream', climate change adaptation into their decision-making. Farmers are often thought to do so intuitively, because many climate change impacts will manifest in similar ways to the weather and climate variability that farmers have always faced. However, there is little evidence to suggest whether farmers are already doing this, how they should go about it, and how hard it might be. Here we show that commercial grain farmers in South Africa ($N = 90$), as a uniquely informative group, are struggling to mainstream climate change risk management despite their apparent incentive, capacity and willingness to adapt. They perform large-scale, highly mechanized, input-intensive grain farming like their peers in higher-income countries (*e.g.*, the United States, Canada, Europe and Australia), but without the government subsidies, crop insurance and irrigation more common in other regions. They are therefore motivated to adapt proactively because they are more vulnerable to the financial harms of weather and climate risks. Our data show that they are explicitly sensitive to the risks of climate change, generally expressing concern for its potential impacts, reporting observed changes, proposing possible adaptations, and expressing the desire to adapt proactively. However, their mental models of climate change ($n = 30$) are linguistically and structurally isolated from their mental models of weather and other 'normal' risks. They are therefore implicitly insensitive to climate change, making it unlikely that they will adapt proactively and rationally to this uncertain risk that they otherwise appear well-equipped to manage.

1. Introduction

Although the framing of climate change adaptation may sometimes imply that it occurs as distinct process of conscious and planned adjustment (Bassett and Fogelman, 2013), researchers have widely recognized that climate change is only one of many stressors that drive multi- and cross-scalar decisions towards varied and competing objectives (Bassett and Fogelman, 2013; Eakin et al., 2016). The integration, or 'mainstreaming', of climate change adaptation into pre-existing decision-making processes has therefore become an important pre-occupation of the adaptation literature across policy domains and scales (Dovers and Hezri, 2010; Howden et al., 2007). Yet the processes of human judgment and decision-making involved in harmonizing the management of climate change with weather, climate variability and other 'normal' risks are understudied, and therefore poorly understood (Clayton et al., 2015; Grothmann and Patt, 2005).

The mainstreaming of adaptation into *institutional* decision-making is widely perceived as challenging, because climate change has features that are mismatched with those of many other risks (Kunreuther et al., 2013). First, predictions of some climatic variables at the local scale are uncertain in both sign and magnitude; this makes 'perceive-predict-act' approaches hard to design and harder to implement. Second, climate change risks are often mismatched temporally and spatially with concurrent objectives (Hallegatte, 2009). Researchers studying climate change adaptation have therefore suggested various approaches for integrating climate change with other priorities, from the explicit integration of climate change risks through structured and robust decision-making protocols (*e.g.*, Kunreuther et al., 2013) to their more implicit integration through broader resilience, transformation and development agendas (*e.g.*, O'Brien, 2012).

However, climate-adaptive decision-making by *individuals* has received much less empirical treatment, especially in 'real world' situations (Dilling et al., 2015; Grothmann and Patt, 2005). This has led to a general failure to understand whether and how individuals will mainstream, and so adapt to, climate change risks. Commercial farmers are characterized as autonomous and largely rational decision-makers who

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are sensitive to weather, climate variability and climate change. They are therefore expected to perceive and mainstream climate change risks more readily than other groups of decision-makers (Grothmann and Patt, 2005; Eakin et al., 2016). Rainfed crop production, in particular, is among the sectors anticipated to be most vulnerable to the impacts of climate change (Lobell et al., 2008). Yet few studies have evaluated farmers' mainstreaming of climate risks, especially *in situ* – that is, within the multi-faceted and uncertain environments in which they actually make risk management decisions.

The commercial grain farmers of South Africa's Western Cape province are, ostensibly, a case in point. Their farming enterprises closely resemble those in higher-income countries (*e.g.*, the United States, Canada, Europe, Australia), as opposed to the smallholder farmers more typical in studies of African agriculture. They perform large-scale, input-intensive, highly mechanized and rainfed grain production (RSA, 2013a) in a semi-arid environment with highly variable rainfall (RSA, 2011). They are relatively well educated, with good access to financial, informational and institutional resources (Wilk et al., 2013). They have also been targeted for more than a decade by risk communication campaigns from local and international agricultural and climate science experts (Findlater, 2013). However, since many are white beneficiaries of South Africa's apartheid legacy, they generally receive little explicit support from government (*e.g.*, few of the subsidies enjoyed by commercial farmers in those higher-income countries and less access to affordable crop insurance) (Bernstein, 2012).

Crucially, these farmers have recently been adopting practices associated with Conservation Agriculture (CA) (RSA, 2013b) – a set of techniques affirmed by the Intergovernmental Panel on Climate Change (IPCC) as contributing simultaneously to climate resilience and food security (Niang et al., 2014). The climate in the Western Cape is expected to become even more variable in the future, with rising temperatures and the potential for decreasing mean rainfall (Ziervogel et al., 2014). Longer and more intense wet and dry spells are strongly anticipated – in fact, the Western Cape is currently experiencing its worst drought in recorded history (City of Cape Town, 2018). These farmers are also less buffered against climate risks than farmers in other South African provinces, who generally have more access to water for irrigation (RSA, 2013a; Wilk et al., 2013). When applied comprehensively, CA's three principles – advanced crop rotations, low soil disturbance (*i.e.*, minimum or no-tillage) and permanent soil cover – tend to increase mean yields (as a function of rainfall), reduce crop yield variability (reducing the risk of crop failure), reduce input costs (*e.g.*, fuel, fertilizer, seed), and increase income diversification (through crop diversification and mixed crop-livestock systems) (Hobbs et al., 2008; Jat et al., 2012; Knowler and Bradshaw, 2007). For these reasons, CA is foundational to the Food and Agriculture Organization's (FAO) Climate-Smart Agriculture and Sustainable Intensification frameworks (FAO, 2013a; FAO, 2013b; Giller et al., 2015).

Driven in part by strong advocacy from the IPCC and FAO, CA has spread quickly in recent years (Kassam et al., 2015). However, preliminary interviews with local experts in the Western Cape suggested that farmers' CA adoption has had little to do with climate risks. Farmers' emphasis on reducing input costs and maintaining livestock has resulted in inconsistent adoption of the three principles, most often sacrificing soil cover and favouring periodic soil disturbance to alleviate surface compaction by animals (Findlater et al., forthcoming). This pattern mirrors the "pragmatic adoption" of CA in other countries with mechanized farming systems (Derpsch et al., 2014; Giller et al., 2015). The dilemma for farmers is that CA's crop yield and climate-resilience benefits take five to ten years to develop, particularly with respect to soil health (*e.g.*, structure, biota, organic carbon), and are undermined by periodic soil disturbance. Where farmers are inconsistent in their practices over time, or fail to adopt the three principles in a coordinated manner, meta-analyses have shown curtailed benefits of CA and even reductions in mean crop yields (Pittelkow et al., 2015; Rusinamhodzi et al., 2011; Van den Putte et al., 2010). For CA to be effective in adapting to climate change, it is therefore imperative that this be a clear objective and that trade-offs be coordinated with other objectives (*e.g.*, livestock, short-term yield maximization). The latter seems unlikely where climate risk management is not mainstreamed.

Here, we shed light on the mainstreaming behaviours of this group of farmers who have the apparent incentive, capacity and willingness to adapt (Bernstein, 2012; Wilk et al., 2013). They are physically vulnerable to climate change (Niang et al., 2014; RSA, 2011), and are gradually adopting a set of CA practices that is nominally climate-resilient if applied proactively and consistently (Pittelkow et al., 2015), but in a manner that undermines its long-term benefits. Using a mental models approach, we test the hypothesis that their perceptions of, and responses to, climate change risks are well-integrated with their management of weather and the myriad other 'normal' risks that present day-to-day challenges in commercial farming. We seek to understand whether they are sensitive to climate change risks – that is, whether they perceive and respond to climate signals. First, we ask whether these farmers are *explicitly* sensitive to climate change risks, as they are to weather ($N = 90$): Do they express concern about climate change risks, along with the willingness to respond to them? Second, we ask whether their decision-making processes are *implicitly* sensitive to climate change risks ($n = 30$): Are their mental models of climate change well-integrated, linguistically and structurally, with those of weather and other 'normal' risks, and thereby actionable?

2. Methods

Using a structured mental models protocol (Section 2.1), we interviewed 90 commercial grain farmers in South Africa's Western Cape province (approximately 10% of the population of such farmers). We first evaluated their *explicit* sensitivity to climate change risks ($N = 90$) by coding their expressed risk perceptions and proposed adaptations (Section 2.2). We then evaluated their *implicit* sensitivity to climate change risks ($n = 30$) by analyzing the extent of linguistic and structural integration between their causal mental models of climate change and those of weather and other 'normal' risks (Section 2.3). The analytical steps are elaborated below and summarized as a flow chart in Fig. S1 in the Supplementary Information. The protocols were designed, piloted and implemented in consultation with partners at the University of Cape Town, Stellenbosch University and the Western Cape Department of Agriculture.

The data were collected by a single interviewer in the two months preceding the grain harvest in late 2013. This corresponded to the end of a three-year period of above-average rainfall, with record wheat yields (RSA, 2013a), so farmers were likely less sensitive to weather and climate change problems than they might otherwise have been. Willing participants were recruited by phone and email through geographically stratified random sampling. Recruitment was facilitated by representatives from the four major co-operatives and agribusinesses that market and distribute grain produced in the region. All interviews were conducted in English. Approximately 20% of those contacted declined to participate, most frequently citing time constraints, but with some suggesting a discomfort with English. None were given any material incentive to participate. All interviews were conducted on participants' farms, in locations where they make decisions about their farming businesses every day.

These farmers generally practiced mixed grain and livestock farming centred on rainfed wheat production. Their ongoing adoption of CA is among the most important changes in practice currently underway in South African commercial agriculture (RSA, 2013b). Participants were scored on their adherence to CA as a measure of climate-resilient best practices, and these scores were incorporated as an independent variable in the statistical analyses described below. In keeping with demographic trends among South African commercial farmers, all of the participants were male, ranging in age from 25 to 62 years ($M = 43.9$, $SD = 9.3$). Their available arable farmland ranged

from 250 to 4500 ha (M = 1443, SD = 880). All participants had finished high school, with the majority (76%) having a university or college degree. A plurality (39%) of participants had completed one- or two-year technical degrees, while one-third (33%) held Bachelor's degrees and a small fraction (3%) held Master's degrees. Though most spoke Afrikaans as their first language, all were conversant in English. These demographics and farm size are generally consistent with South African commercial farming more broadly, and grain farming in particular, though with less irrigation than in other areas (RSA, 2013a; Wilk et al., 2013).

2.1. Mental models protocol

To elicit the internal representations of reality that participants accessed in managing weather and climate change risks, the interview script was designed in accordance with established mental modeling methods (Jones et al., 2011; Morgan et al., 2002), and followed a 'broad-to-narrow' structure. The elicitation was performed in two stages within each interview. First, participants were asked to list and elaborate on important risks that they faced in their farming businesses. These were documented by the interviewer on sticky notes pasted to an erasable white board. The landscape of farming risks was therefore defined by the participants, with the interviewer providing only standard prompts relating to broad categories (*e.g.*, on the farm, beyond the farm, short term, long term, the economy, the environment). The interviewer then used vague questions (*i.e.*, "What comes to mind when you hear the term….") and standardized follow-ups (*e.g.*, "What is the effect of….") to prompt participants to elaborate on causal relationships relevant to specific domains of interest – particularly weather and climate change risks, and agricultural practices. The elicitation method was therefore indirect, meaning that participants were unaware that the interviewer sought their mental models of weather and climate change risks. Whereas direct elicitation may encourage participants to identify and resolve inconsistencies and competing logics in their mental models, the indirect method preserved these patterns of *in situ* thinking.

The script culminated in a final section introducing climate change, if the participant had not already done so, and exploring its on-farm implications in depth. Climate change-related language was excluded from the rest of the interview script, in an attempt to avoid triggering the most overt forms of motivated cognition described in other studies of climate change risk perceptions (*e.g.*, stereotype threat (Lewandowsky et al., 2015) or cultural cognition (Kahan, 2015)). However, it was followed up whenever mentioned by the participant, as with weather and climate variability. The script therefore explicitly explored risks in farming, while implicitly evaluating how weather and climate change were enmeshed in broader processes of farm-level risk management.

2.2. Analysis of explicit climate change risk perceptions and proposed adaptations (N = 90)

To assess participants' explicit sensitivity to climate change risks, each of the 90 interviews was comprehensively coded for references to climate change. First, to measure the extent to which participants had to be prompted to speak of climate change, each participant was assigned a score corresponding to the section of the interview script in which they first raised the topic (on a ten-point scale, from zero for those who raised it prior to the first question about risks, to nine for those who did not speak of it until the interviewer asked directly about it in the final section of the script). Word-search coding was used to identify all statements relating to weather and climate change across the 90 transcripts, using an exhaustive set of keywords. Statements referring to climate change were then coded to create a set of ordinal variables representing different measures of climate risk perception: (1) belief that climate change is occurring or will occur (*i.e.*, none, partial, full); (2) observed climatic changes, past or ongoing, attributable to climate change (*i.e.*, no, maybe, yes); (3) the sign of its likely overall effect on their farm (*i.e.*, negative, neutral, positive); (4) expressed levels of concern for these impacts (*i.e.*, none, low, medium, high); and (5) the perceived manageability of the impacts (*i.e.*, unmanageable, partially manageable, fully manageable). Finally, each participant's proposed adaptations to climate change were compiled and compared. For consistency, the same researcher conducted all of the coding.

Correlations among these different measures of climate risk perception were used to evaluate their consistency, as well as to identify relationships between the explicit expressions of risk perception and those implicit in the mental models analysis described below. Nonparametric, rank-based Spearman's rho was chosen as the primary statistical measure of correlation, since most variables were ordinal with few levels (two to five). SPSS automatically adjusted the results for tied ranks. Kendall's tau-b was considered as an alternative, but the results appeared broadly similar to those of Spearman's rho for the findings reported in this paper. Participants' explicit climate-sensitivity, as evaluated here, was then compared and contrasted with their implicit climate-sensitivity, as evaluated below.

2.3. Analysis of participants' mental models (n = 30)

To derive their mental models of weather and climate change risks, the interview transcripts of a subset of participants (n = 30) were comprehensively coded for causal statements related to weather and climate change. Only 30 interviews were selected for modeling because of the time-consuming nature of the process and the diminishing utility of additional mental models; generally, 30 are considered sufficient to capture the breadth of thinking in a relatively homogeneous group (Morgan et al., 2002). The candidates for modeling were selected on the basis of their farming practices (to capture their variety), their language proficiency, and the extent to which they had elaborated on simple answers when prompted, as a measure of interview quality. The language criterion may have led to some bias in the modelled subset, since the English language proficiency of Afrikaans-speaking farmers likely depends in part on their social integration; however, the inference of causal relationships during analysis was expected to be more precise where participants were comfortable expressing nuance in English.

The coded causal relationships were then visualized as influence diagrams consisting of nodes (concepts) connected by directional edges (causal relationships between concepts). For instance, SA050 said, *"When you really go the minimum [tillage] way, you get more pests like snails that live underneath that material."* Therefore, his mental model showed that minimum tillage causes an increased risk of pests (and specifically snails). For consistency, all coding was conducted by a single researcher. The influence diagrams were structured left-to-right,

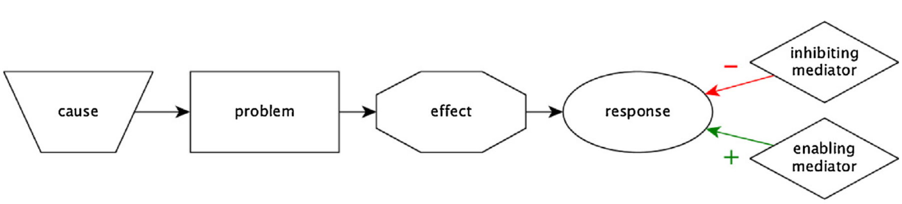

Fig. 1. Simplified representation of the mental model structure. Nodes (concepts) are displayed as shapes, and edges (causal relationships) are displayed as directional arrows. Causes (*e.g.*, climate cycles) lead to problems (*e.g.*, rainfall variability) that create negative effects (*e.g.*, low soil moisture). Participants manage these effects through responses (*e.g.*, increasing soil cover) that are mediated by non-weather variables (*e.g.*, inhibited by competition for crop residues as livestock feed).

stemming from problems of weather, climate variability and climate change, producing negative effects that evoked specific responses mediated by non-climatic factors. Fig. 1 shows a simplified example of the causal mental model structure. For example, the participant may have stated (whether sequentially or at various points in the interview) that climate cycles cause interannual rainfall variability (a problem), leading to low soil moisture (an effect), which can be managed by increasing soil cover using crop residues – a response which is mediated (or in this case inhibited) by the competing need to use crop residues as livestock feed. Fig. S2 in the Supplementary Information shows a full-scale example of one participant's mental model.

Each node (or concept) was then classified as either 'normal' or 'climate change' depending on the cause that the participant stated or implied within the context of the interview (*i.e.*, weather/climate variability versus climate change). Within each participant's mental model, there were therefore two major branches stemming from 'normal' and climate change causes, respectively. The 'normal' branch comprised causal relationships originating from problems of weather and climate variability attributed to climatic processes consistent with historical conditions. In contrast, the climate change branch consisted of causal relationships originating from weather and climate problems attributed to present or future global climate change, whether or not such change was explicitly referred to as anthropogenic. Where specific concepts (*i.e.*, problems, effects, responses and mediators) were referenced under both conditions, they were categorized as 'normal' nodes, and thus established causal relationships between the 'normal' and climate change branches. The two branches were therefore more interconnected where participants spoke of weather and climate change in similar terms.

2.3.1. Analysis of structure and interconnectedness

To evaluate the relationship between weather and climate change in participants' mental models, we analyzed the structure of each branch and the interconnectedness between them. We initially compared and contrasted the overall structure and size of each branch, including the frequency of intuitive leaps (*e.g.*, where participants neglected to identify the specific problems or effects that they intended to address with proposed risk management responses). For instance, in Fig. 2, there are three 'normal' responses (fallow land, increase soil cover and minimum soil disturbance) stemming directly from the 'climate change' cause with no identification of the intervening problems or effects. The interconnectedness of the 'normal' and climate change branches was then assessed using two simple measures: (1) the number of connections between the two branches; and (2) the amount of overlap between the two branches when each mental model was algorithmically clustered to illuminate natural "communities" of nodes (concepts). We finally analyzed the variation in these two measures of interconnectedness with respect to participants' explicit climate change risk perceptions and CA practices, as previously coded.

For the first measure of interconnectedness, we simply counted the number of edges (causal relationships) connecting 'normal' and climate change nodes within each participant's mental model. For example, Fig. 2 shows a mental model with ten connections between the two branches, which was towards the upper end of the range, while Fig. 3 shows a climate change branch with no connections to the 'normal' branch. This provided a rough measure of the extent to which the two branches were integrated. We corroborated this using a simple form of network analysis to compare the importance of connections within each branch to those between them. The Girvan-Newman edge betweenness clustering algorithm (Girvan and Newman, 2002), as implemented in the yEd network graphing software, was used to identify natural "communities" of nodes (Fig. S3 in the Supplementary Information shows an example of such a clustered mental model followed by a more detailed description of the algorithm). We counted the number of climate change nodes appearing in clusters other than that containing the 'climate change' cause, as well as the number of 'normal' nodes appearing in the climate change cluster. The extent of this combined overlap between the 'normal' and climate change branches thus provided a second measure of their integration – that is, it revealed the extent to which participants' climate change branches were distinct and cohesive clusters, separate from the 'normal' branches.

2.3.2. Analysis of linguistic framing

The analysis of linguistic framing followed from that conceived in Findlater et al. (forthcoming), in which we found that participants framed weather and climate change risks using six exhaustive and mutually exclusive 'languages' (Table 1). Following the identification of these categories, each node in each participant's mental model was coded into one of the six languages (see Fig. 2 for a partial mental model coded for language). In Findlater et al. (forthcoming), we found that participants' adoption of CA practices was strongly related to their framing of weather risks. Here, we instead compare participants' linguistic framing of the weather risks to that of climate change, as an indication of their underlying cognitive framing. Using paired-samples *t*-tests, we analyzed the differences between the weather and climate change branches in terms of the number of nodes coded into each language as a proportion of the total nodes in each branch.

3. Results

3.1. Explicit climate change risk perceptions ($N = 90$)

To evaluate whether these farmers were *explicitly* sensitive to climate change risks, we analyzed their expressed risk perceptions as coded into six variables: promptedness, belief, concern, observed changes, overall predicted effect, and manageability. Many participants raised the topic of climate change with little prompting. During the initial risk elicitation exercise, 17% of participants spoke of climate change when asked broadly about "risks or concerns that you face as a farmer." A further 49% of participants referred to climate change in response to standard prompts about risks related to "weather" or "environment". Overall, two-thirds (66%) of participants raised the topic before it was formally introduced towards the end of the interview script. "Promptedness" is thus a quantitative measure of the extent to which participants had to be prompted by the interviewer before they spoke of climate change – *i.e.*, the higher the promptedness value, the later in the interview the participant mentioned the topic. In making unprompted references to climate change, participants used terms like "changing weather patterns", "global warming", "global heating", "climate control", and most often "climate change" itself.

Most participants believed in present or future climate change, expressed concern for its likely impacts, and reported having already observed changes in climate. Specifically, the vast majority of participants (84%) expressed at least partial belief in present or future climate change. When asked directly, nearly two thirds (62%) expressed strong belief and a further quarter (22%) expressed partial belief. Only a small minority (16%) of participants expressed explicit disbelief. An even greater share (91%) expressed at least some concern for climate change's potential impacts, with a minority (20%) highly concerned. Many participants reported ongoing changes to their local climate, commonly including increasingly intense rainfall events, more variable rainfall, hotter summers, colder winters, and shifts in the seasonality of rainfall (*i.e.*, starting and ending later). These closely match those climate trends identified as important for the Western Cape in parallel expert interviews. Nearly two thirds (60%) reported having observed environmental changes that they explicitly attributed to climate change. A further 14% reported changes that they thought might be attributable to climate change, but with a high level of uncertainty. Only one quarter (26%) of participants reported having observed no environmental changes that they might attribute to climate change.

As an example of an explicit statement about climate change, SA087 was firm in expressing his belief: "*It's already busy changing, definitely*….

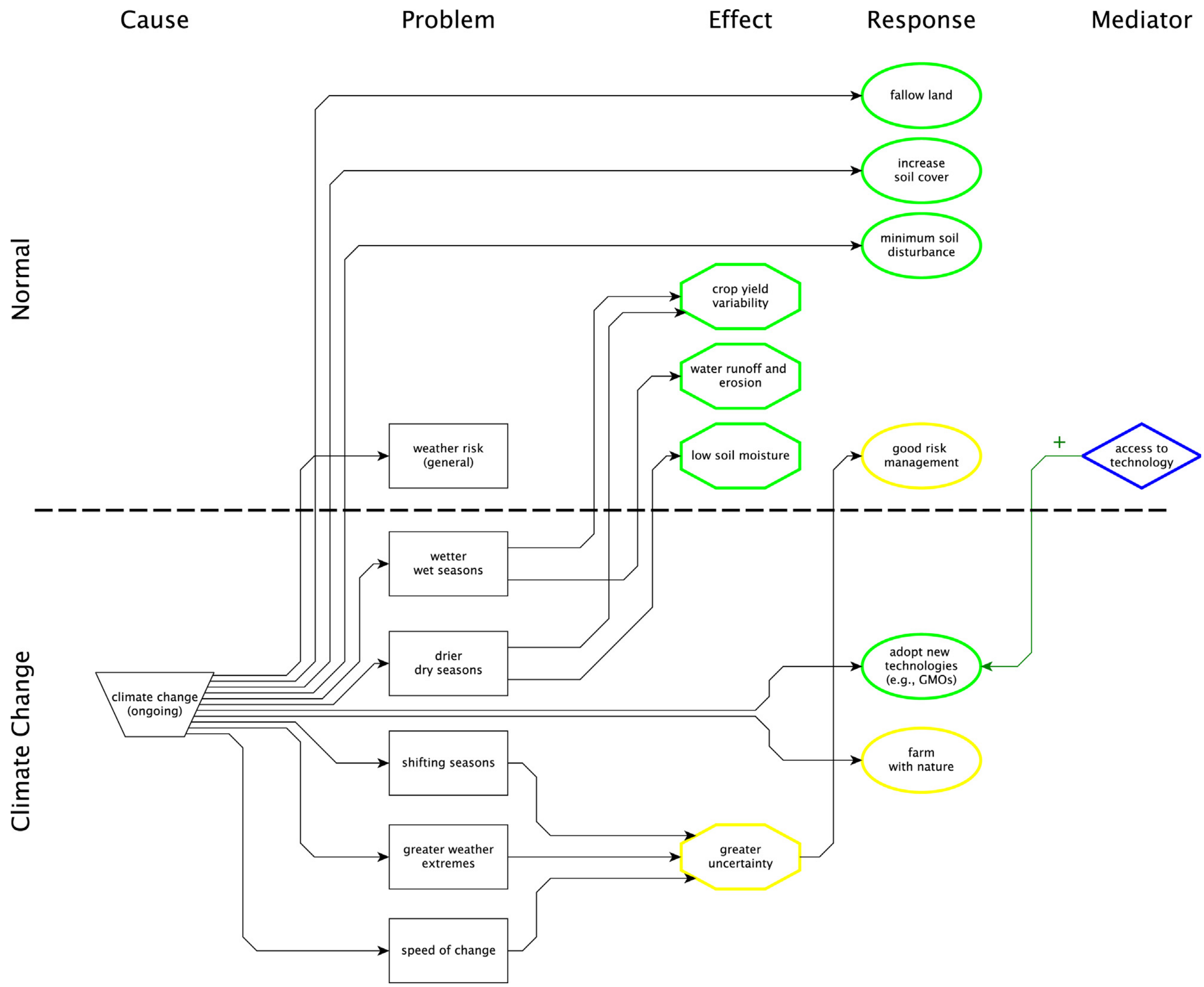

Fig. 2. Partial mental model showing the climate change branch and close integration with the 'normal' branch. This farmer had the second highest number of inter-branch connections of any participant. The full climate change branch is shown, along with each point of initial connection to the 'normal' branch. The colour of each node indicates its language classification (*i.e.*, green for agricultural, yellow for cognitive, and blue for economic). This farmer's larger 'normal' branch is not shown in the figure. Please see Fig. S2 in the Supplementary Information for an example of a full mental model including both branches. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

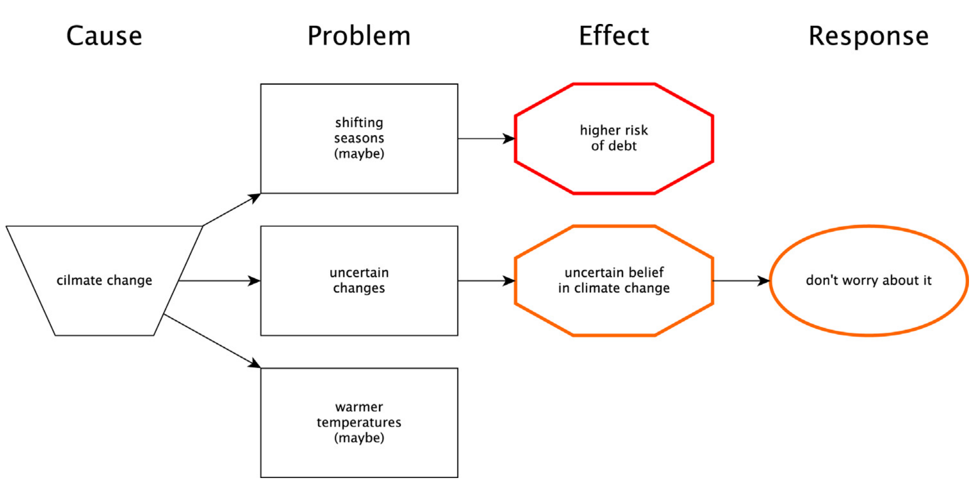

Fig. 3. Partial mental model showing the climate change branch and no integration with the 'normal' branch. This farmer was one of four participants with no inter-branch connections. The colour of each node indicates its language classification (*i.e.*, orange for emotional, and red for survival). Only the climate change branch is shown. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

Table 1
Six languages of weather and climate risks, as evident in participants' mental models (reproduced from Findlater et al. (forthcoming)). No mediators were expressed in survival language, and thus no example of such is listed.

Language	Definition	Key Examples (Effect, Response, Mediator)	Intersecting Languages
Agricultural	Related to the practice of agriculture	Crop failure; Minimum tillage; Weeds	
Cognitive	Related to human cognition, decision-making or problem-solving	Increased uncertainty; Better planning; Lack of reliable information	
Economic	Related to farm-level, national or global economic processes	Financial hardship; Diversification beyond farming; Product prices	Survival
Emotional	Related to human emotion, motivation or values	Anxiety; Faith in God; Distrust of others	Survival
Survival	Related to the threat of farm failure	Loss of farm; Sell farm; N/A	Economic, Emotional
Political	Related to local, provincial or national politics	Increased political support for farmers; Lobbying for support; Land reform measures	

Adapt or die." In contrast, SA114 adamantly disbelieved in the idea: *"That's bullshit man, totally. That's a buzz word."* Such expressions of belief, concern and observed climatic changes were not necessarily consistent with each other. For example, SA113 initially scoffed at the idea of climate change: "*Climate? Change? Hah. Many people talk about it, but I don't think it's so.*" However, when asked whether or not he was concerned about its potential effects, he said, *"I think so, yes. We will get less rain, they said, we will get less rain. And when you get less rain, you must change your farming."* The consistency and malleability of expressed climate change risk perceptions are further evaluated in the Supplementary Information.

There were statistically significant relationships among these measures of climate change risk perception (Table 2). Strong correlations were found between belief in present or future climate change, concern for its likely future impacts, and observed climatic changes. Earlier and unprompted references to climate change were also correlated with those three measures, suggesting a relationship between the extent to which climate change risks were top-of-mind and their perceived severity. No significant correlations were found between these expressed climate change risk perceptions and region, education, age or farm size. Overall, we found that by all measures, most participants were explicitly sensitive to climate change risks. That is, they were explicit in their desire to proactively respond to climate change risks by implementing appropriate risk management strategies. Even those who plainly disbelieved in climate change nonetheless usually expressed some concern for its impacts and were open to proactive risk management.

3.2. Explicit manageability of climate change risks

Participants generally predicted that the overall effect of climate change on their farm would be negative – *i.e.*, that it would make farming more difficult, for example, by increasing water stress or reducing average crop yields. However, most thought that they could sufficiently manage its impacts through largely proactive changes in agricultural practice and better planning. Specifically, more than two thirds of participants (71%) perceived that climate change would have broadly negative impacts at the farm level, while one quarter (23%)

Table 2
Non-parametric correlation matrix for climate change risk perceptions. Using Spearman's rho, the table shows the strength of relationships among the various measures of climate change (CC) risk perception ($N = 90$). These ordinal variables were derived from the systematic coding of participants' statements about climate change throughout their interviews. Promptedness is an indication of how much prompting, by the interviewer, was needed before the participant raised the topic of climate change.

Correlation Matrix (Spearman's rho)

	Promptedness	CC Belief	CC Concern	CC Observed	CC Overall Effect
Promptedness	1.000				
CC Belief	-.385 ***	1.000			
CC Concern	-.400 ***	.590 ***	1.000		
CC Observed	-.250 *	.520 ***	.425 ***	1.000	
CC Overall Effect	-.022	-.153	-.349 **	-.025	1.000
CC Manageability	-.022	.126	-.091	.112	.201 †

† $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$ (two-tailed)
$N = 90$

Correlation	Significance
$r_s < 0$	$p < .05$
$r_s > 0$	$p < .05$

thought that the impacts would be neutral or mixed, and a small minority (6%) believed that climate change would have broadly positive effects (*e.g.*, that it would increase mean rainfall and thus improve crop yields). However, more than two-thirds of participants (71%) thought that they could manage climate change impacts at the farm level through adaptation, and a further 20% thought that the impacts would be somewhat manageable. A small minority (9%) predicted that negative climate change impacts would be unmanageable. There was significant correlation between the predicted overall effect of climate change and concern for its likely impacts (Table 2), but this predicted overall effect was not significantly correlated with belief or observed climatic change.

In keeping with its widely perceived manageability, most participants readily listed possible ways of adapting to climate change, both unprompted and prompted. Many indicated that the ongoing adoption of CA, or its component practices, was climate-adaptive. This explicit recognition of CA as an adaptation was positively correlated with agriculture-specific education ($r_s(88) = .270$, $p = .010$). The perceived manageability of climate change risks was then understandably correlated with participants' CA practices. That is, farmers who had more thoroughly adopted CA were more likely to consider climate change risks to be manageable. Specifically, perceived manageability was significantly correlated with the uptake of advanced crop rotations ($r_s(88) = .216$, $p = .040$) and permanent soil cover ($r_s(88) = .213$, $p = .044$), though not with minimum soil disturbance ($r_s(88) = -.002$, $p = .988$). There were no significant correlations between the perceived manageability of climate change impacts and other measures of climate change risk perception, age, education or farm size.

Participants each proposed between zero and six specific adaptations ($M = 2.2$, $SD = 1.3$), though most such adaptations were offered by only a small number of participants (Fig. 4). Apart from CA and its components, which were explored at length within the interview script, the only adaptations that were proposed by more than 10% of participants were the adoption of new crop cultivars (33%) and the increased reliance on livestock for income stability (13%). The number of specific adaptations proposed by each participant was positively correlated with education ($r_s(88) = .355$, $p = .001$), the perceived manageability of climate change risks ($r_s(88) = .242$, $p = .022$), and earlier unprompted references to climate change ($r_s(88) = .243$, $p = .021$). The number of adaptations proposed was negatively correlated with small farm size (less than 500 ha) ($r_s(88) = -.218$, $p = .039$). No significant correlations were found between the number of proposed adaptations and region, age, or other measures of climate change risk perception.

All of the proposed adaptations were collectively also described as effective responses to the risks created by weather and climate variability, but usually by participants other than those who had characterized them as adaptations to climate change. For instance, SA128

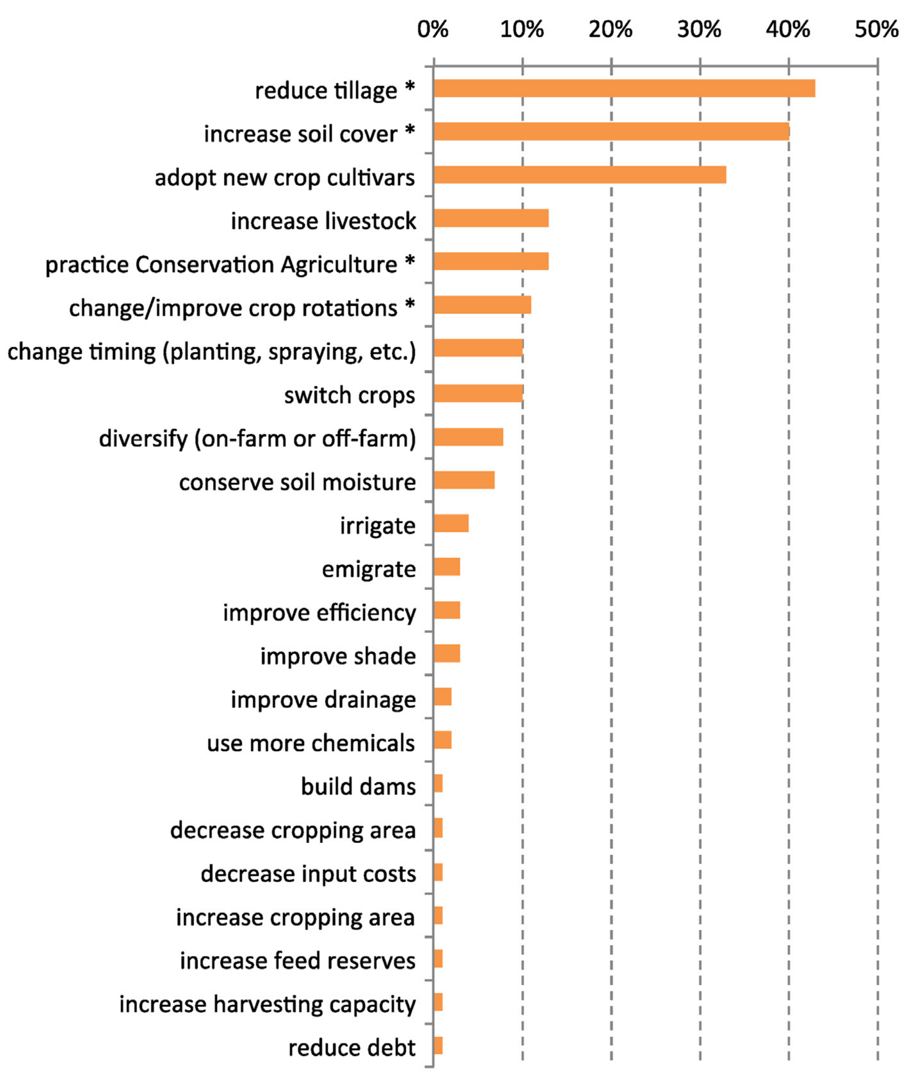

Fig. 4. Frequencies with which participants ($N = 90$) proposed each climate change adaptation. *Components of Conservation Agriculture that were specifically prompted by the interviewer, though not in reference to climate change.

described two such adaptations, which other participants had mentioned as possible responses to weather and climate variability, but which he had not: *"[If] our summers get hotter, I can put up more shade for my animals. And if our summers get drier, I can build more dams so that they have enough water during the dry periods."* However, the responses identified as adaptations tended to be more drastic and to require more forward planning than most typical responses to weather and climate variability. Many of the changes in farming practice listed in Fig. 4 (*e.g.*, those related to CA, income diversification, debt reduction, irrigation and drainage) require long-term investments in knowledge, equipment and infrastructure. Others require long-term investments industry-wide (*e.g.*, new crop cultivars, development or localization of equipment and crop rotation systems). Few could be implemented reactively without risking their effectiveness or incurring greater costs. Further, these farmers tend to change practices incrementally through experiential learning. CA adoption began in the mid-1990s, but has only recently become more widespread – most farmers now use some form of minimum-till planter, but many still periodically rip the soil to alleviate compaction and few maintain permanent soil cover to the standard recommended by the FAO.

3.3. *Structural isolation of climate change from weather (n = 30)*

Having established that most participants were *explicitly* climate-sensitive (*i.e.*, they were nearly all concerned about its likely impacts, often reported having observed changes in climate, and readily proposed climate-adaptive responses), we assessed their *implicit* climate-sensitivity by evaluating the mainstreaming of climate change risks into their management of weather and other 'normal' risks. There was little structural integration of participants' mental models of 'normal' and climate change risks, both as measured naïvely by the number of connections between these branches, and as measured by the amount of overlap when clustered algorithmically. Fig. 5 illustrates the broad distinction between the 'normal' and climate change branches of participants' mental models. The 'normal' branches (*i.e.*, weather and climate variability) were large and well developed, with many connections between nodes, overlapping and competing responses. Notably, they contained myriad mediators of response, which were consistently associated with the management of other normal risks beyond weather and climate variability. In contrast, the climate change branches were small, with short causal chains, rarely including many responses or any mediators of response. The 'normal' branches were therefore well-integrated with other decision-making processes – *i.e.*, there were far more responses and mediators than there were problems and effects (Fig. 6). The opposite was true for climate change – *i.e.*, there were far more problems and effects than responses and mediators.

The climate change branches contained more intuitive leaps – *e.g.*, where they described risk management responses without indicating the specific problems or negative effects that these responses were intended to address. Fig. 5 illustrates the prominence of intuitive leaps in the climate change branches, with many effects and responses linked directly from the climate change cause. The proportion of such intuitive leaps, relative to the size of the branch, was much higher for climate change (17% of edges, excluding mediators) than for the 'normal' branch (3% of edges, excluding mediators). Many participants thus described adaptations to climate change without providing a clear rationale for their choices. For instance, SA123 suggested that he could manage the risk of climate change by "farming with nature," without specifying any of the problems that would be caused by climate change and would therefore be attenuated by this response.

The distinction that participants made between weather and climate change was reflected in the small number of connections between the climate change and 'normal' branches of their mental models. Fig. 5 shows that there were few connections between the two branches compared with the number of connections within each branch. Figs. 2 and 3, in the methods section, show specific examples of well-connected and disconnected climate change branches, respectively. The two branches were connected where participants described similar problems, effects, responses or mediators of response stemming from the two causes. For instance, both climate change and climate variability might cause droughts leading to low soil moisture. Climate change might also cause heavy rainfall and subsequent soil erosion, which could be managed by improving soil cover – a response that also normally manages the negative impact of high soil surface temperatures in 'normal' summers. The number of interconnections between the two branches ranged from zero to thirteen per participant ($M = 3.7$, $SD = 3.1$), with 16% of participants describing no such connections at all. The distribution was right-skewed – that is, most participants drew few connections, with only 13% describing more than six. The number of connections was positively correlated with earlier and unprompted introductions of the topic of climate change by the participant ($r_s(28) = .472$, $p = .007$), and with participants' expressed level of belief in present or future climate change ($r_s(28) = .502$, $p = .004$) and their concern for its likely impacts ($r_s(28) = .455$, $p = .010$). It was not significantly correlated with the other measures of explicit climate change risk perceptions.

The scarcity of connections between the branches showed that there was little expressed overlap in the problematic effects and proposed responses stemming from 'normal' and climate change risks within each participant's mental model. The small number of climate change-

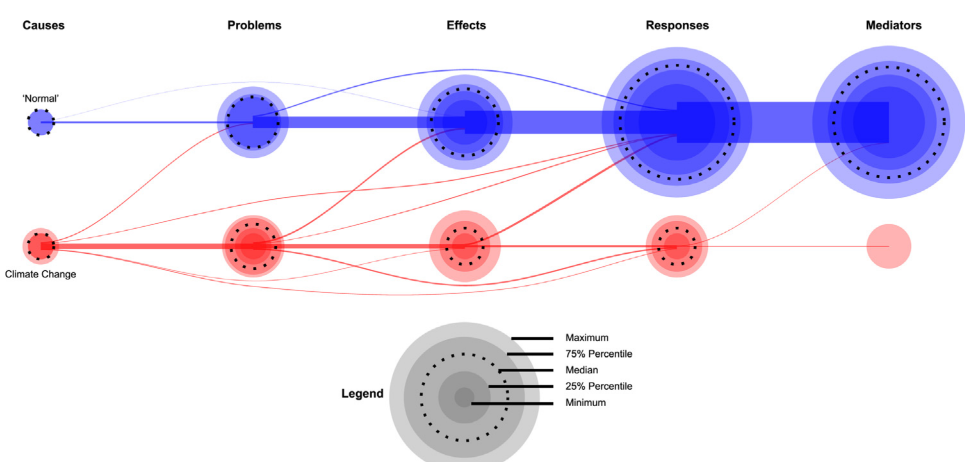

Fig. 5. Participants' aggregate mental models ($n = 30$), showing the 'normal' and climate change branches. This figure demonstrates the relative isolation of climate change logic from that of weather and other 'normal' risks. Within these mental models, nodes (concepts) are connected by edges (causal relationships). Thus, the 'normal' and climate change branches are connected where participants spoke of weather and climate problems, effects, responses and mediators of response in similar terms. Participants' climate change logic exhibited a greater frequency of intuitive leaps – for example, they more often described climate-adaptive responses without specifying the problem or negative effect that they intended to manage. The area of each circle is proportional to the average number of nodes in each model section (with distribution shown by shading). The width of each flow is proportional to the mean number of edges connecting the paired model sections. The size of the circles is not proportional to the width of the flows.

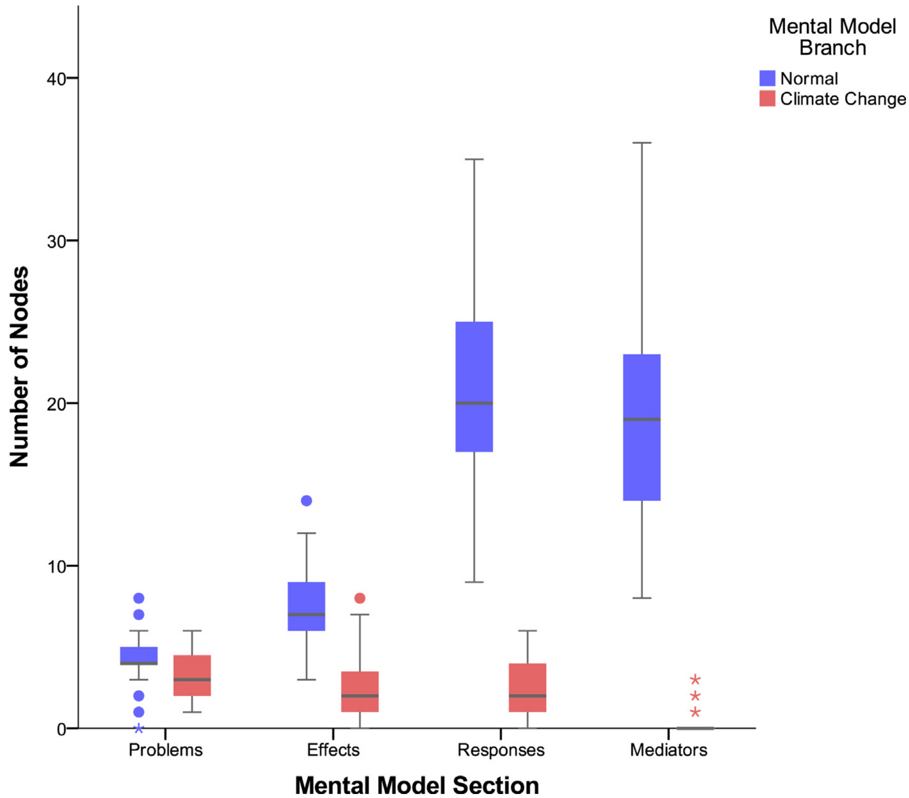

Fig. 6. Boxplot comparing the size of the 'normal' and climate change branches for each section of participants' causal mental models (n = 30).

specific responses was only slightly augmented by connections from negative climate change effects to 'normal' responses. On average, each climate change effect was connected to less than half as many 'normal' responses (M = .31, SD = .52) (t(62.2) = 3.375, p < .001) as climate change-specific responses (M = .88, SD = .97). This suggests that most proposed responses to climate change were novel within each farmer's mental model, despite the finding above that all of these proposed adaptations were also considered 'normal' responses within the group as a whole. Moreover, responses to climate change effects were scarce overall compared with those to the 'normal' effects of weather and climate variability. On average, participants described nearly twice as many possible responses to each 'normal' effect (M = 2.01, SD = 1.55) as to each climate change effect (M = 1.19, SD = .97) (t(85.591) = 4.509, p < .001). Many connections from climate change effects to 'normal' responses were related to the three CA practices – CA nodes were present in every mental model because of their prominence in the interview script and were commonly recognized as being climate-adaptive. However, there were no significant correlations between the number of connections and participants' level of CA adoption.

For participants who had no connections between the two branches, there was a clear lack of integration, but for those whose branches were somewhat connected, algorithmic clustering further illuminated the extent of their integration. Since problems, effects and responses stemming from climate change were often poorly connected to the 'normal' branch, the algorithm naturally grouped climate change nodes separately from 'normal' nodes. The extent to which the 'climate change' cluster included 'normal' nodes (and vice versa) thus provided another simple measure of integration. By this measure, one third (33%) of participants exhibited no integration between the two models. Predictably, models with fewer interconnections tended to have less overlap (r_s(28) = .710, p = .000). No significant relationship was found between the size of the climate change model and the amount of overlap, though the two participants with complete overlap had the smallest climate change models (four nodes each). The amount of overlap was positively correlated with participants' earlier and unprompted introductions of the climate change topic (r_s(28) = .406, p = .023), but not with any other measures of explicit climate change risk perception.

3.3.1. Linguistic isolation

To assess the extent to which climate change risks were framed similarly to weather and climate variability, we extended the analysis of linguistic framing performed in Findlater et al. (forthcoming). In that study, we found that participants spoke of weather and climate change risks using six "languages" indicative of distinct cognitive framings: agricultural, cognitive, economic, emotional, political and survival (see Table 1 for definitions and examples). In the present analysis, we found clear differences in the linguistic framing of the 'normal' and climate change branches of participants' mental models. Overall, participants spoke of climate change in different terms than they did weather and climate variability, especially in the prevalence of cognitive language (*i.e.*, describing challenges in cognition, decision-making, uncertainty and access to information). The proportions of each language within participants' climate change branches were far more variable than those of their 'normal' branches, in part because the climate change branches tended to contain far fewer nodes (concepts). Nonetheless, the statistical analyses revealed significant and meaningful patterns.

Participants' logic related to climate change contained more cognitive language and less agricultural and economic language than that related to weather (Fig. 7). These differences were confirmed through paired-samples t-tests for each language, which compared the number of nodes coded into that language as a proportion of the total within each farmer's 'normal' and climate change branches, respectively. We excluded mediators of response from this analysis because of their very infrequent occurrence in the climate change branches – only three participants described any such mediators. For instance, we found that there were significantly higher proportions of cognitive nodes (concepts) in the climate change branches of farmers' mental models

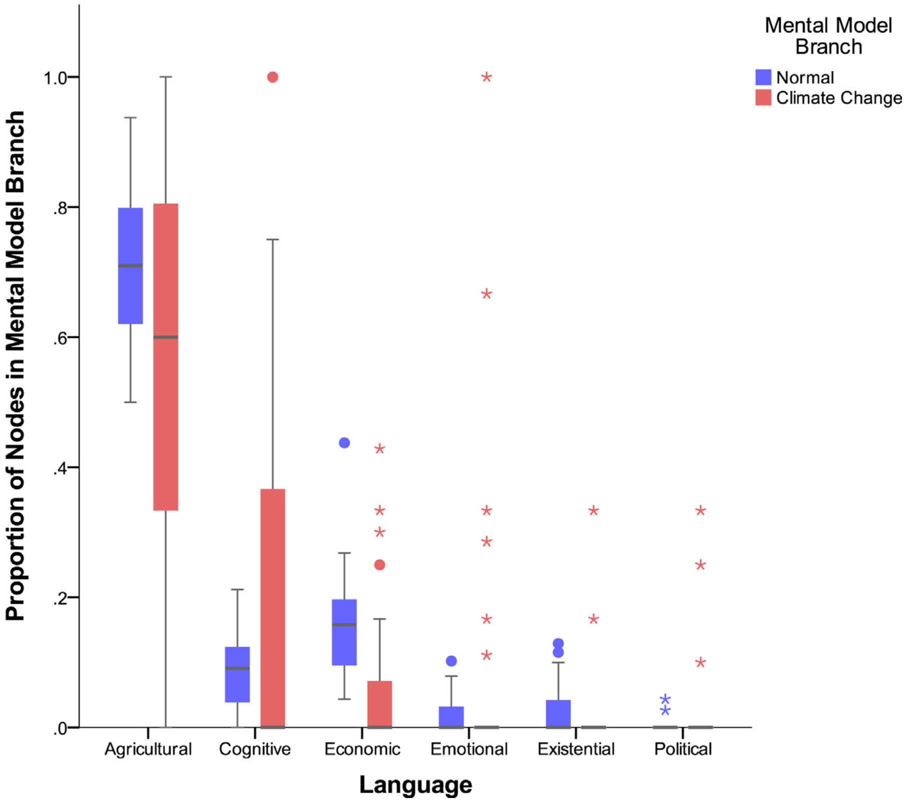

Fig. 7. Boxplot of the number of nodes (concepts) in participants' mental models (n = 30) that were coded into each 'language'. These are shown as a proportion of all nodes in each mental model branch (*i.e.*, 'normal' versus climate change). This figure excludes mediators of response, because of their very low frequency in participants' climate change branches.

(M = .21, SD = .28) than in the 'normal' branches (M = .08, SD = .06) ($t(28) = -2.405$, p = .023), reflecting the novel risks of climate change, their greater uncertainty, a lack of reliable information, and consequently more difficulty in planning and problem-solving. In contrast, there were lower proportions of economic nodes for climate change (M = .07, SD = .14) than 'normal' (M = .16, SD = .08) ($t(28) = 2.900$, p = .007), reflecting the difficulty that participants had in articulating specific effects and responses for climate change risks. There were similarly lower proportions of agricultural nodes in the climate change branches (M = .58, SD = .33) than 'normal' (M = .71, SD = .11), though the test statistic was not quite significant ($t(28) = 2.040$, p = .050).

Such differences in language were also evident within the narrower "effects" and "responses" sections of participants' mental models. The set of relevant boxplots may be found in Fig. S4 in the Supplementary Information. Agricultural language was more often used to describe 'normal' effects ($t(25) = 2.070$, p = .049) and economic language to describe 'normal' responses ($t(27) = 6.691$, $p < .001$), when compared with climate change effects and responses, respectively. Cognitive ($t(27) = -2.077$, p = .047) and emotional ($t(27) = -2.063$, p = .049) languages were more often used to describe climate change responses than 'normal' responses, though most participants had no emotional responses in either branch. Within the climate change branch, emotional and survival nodes were well correlated ($r_s(28)$ = .401, p = .025).

4. Discussion and conclusions

The farming techniques and theoretical adaptive capacity of South Africa's commercial grain farmers are similar to those in higher-income countries, but they have greater incentive to proactively manage climate risks because of the absence of government subsidies and the scarcity of crop insurance. They have long been targeted by specific campaigns stressing the importance of climate change impacts and adaptation within the country's highly variable and semi-arid climate. They need not be convinced that climate is dynamic; they do not conceive of 'normal' weather and climate variability as stable and predictable. They experience and respond to daily fluctuations in weather, and multiple overlapping climate cycles on various timescales, some of which may only recur once or twice during their working lives. They are gradually adopting a set of CA practices that is nominally climate-resilient if applied proactively and consistently. They therefore generally perceive themselves as capable of adapting to climate change. They also perceive themselves as highly adaptive to myriad other uncertain long-term risks related to agronomics, economics and politics, and they largely understand the climate-resilient benefits and shortcomings of their current practices. This combination of capacity, incentive and willingness to act make this an ideal case from which to draw insight into farmer behaviors more broadly, and responsiveness to climate change in particular. At first glance, this group appears more likely than most others to adapt to climate change proactively.

However, climate change is isolated from farmers' mental models of everyday risks, both linguistically and structurally, despite the recognition that many relatively normal (and typically proactive) agricultural responses would likely help to lessen its impacts. Their CA practice is characteristic of the "pragmatic adoption" observed in other mechanized farming systems (Derpsch et al., 2014; Giller et al., 2015), undercutting longer-term climate-resilient benefits. To the extent that climate change risks are managed proactively, they are conceived as separate from the deeply intertwined decision-making processes used to manage and make trade-offs among objectives related to weather, climate variability and other normal risks (*e.g.*, financial, labour, political, personal). The causal relationships that farmers describe as stemming from climate change are rarely developed well enough to include many responses or any of the mediators of response normally associated with other objectives in farmer decision-making. Most farmers speak of climate change in largely abstract terms, recognizing systemic impacts, but drawing few causal connections to existing processes.

The unique cognitive challenges created by climate change are reflected in the higher proportions of cognitive language and the lower

proportions of agricultural and economic language in farmers' climate change mental models. Their mental models of climate change therefore appear less actionable, despite their explicit concern for its impacts, their reported observations of ongoing changes, and their proposed adaptations. For instance, their CA adoption is correlated neither with their explicit climate change risk perceptions, nor with the level of integration between the 'normal' and climate change branches of their mental models. In their expressed risk perceptions, these farmers are *explicitly* climate-sensitive – perceiving climate change risks and intent on responding. But the isolation of climate change from their mental models of weather, climate variability and other 'normal' risks suggests that they are *implicitly* insensitive. That is, these farmers have not mainstreamed climate risks into broader decision-making processes, making it less likely that their choices will account for climate risk management, as well as trade-offs between this and other objectives.

This cognitive isolation may result, in part, from broader societal framings. Farmers have little previous experience with climate change. Their understanding is therefore strongly influenced by agricultural and climate change risk communication from experts, which is incongruent with the experiential learning that normally shapes farmer decision-making. This imparted expert knowledge seems to be incorporated uneasily and abstractly into their mental models of environmental risks, contributing to a mismatch between the cognitive frames that they use for 'normal' risk management and those that they use for climate change. In part, they seem to distrust expert knowledge that is not well-situated within the specific context of their farms, consistent with findings in other regions suggesting that farmers distrust of knowledge from outsiders (Frank et al., 2011). Despite their frequent recognition of changes similar to those that experts predict, these South African farmers remain uncertain and skeptical of climate predictions and of the appropriateness of recommended adaptations. Outreach that emphasizes the consensus among experts, as opposed to farmers' lived experiences, may thus unintentionally drive their weather and climate change frames further apart (as implied by Moser (2010)).

Having little experiential knowledge of climate change, they seek novel solutions to a novel problem. While many proposed adaptations are unique to climate change within individuals' mental models, even those that may seem most extreme (*e.g.*, crop-switching, emigration) are offered by other farmers as responses to weather and climate variability, either directly or in combination with other stressors (*e.g.*, land reform). Despite the cognitive isolation of climate change, farmers' proposed adaptations are therefore implicitly reasonable responses to 'normal' environmental, economic, social and political risks. These responses, however, tend to require more systemic, proactive and longer-term changes in knowledge, planning, farming practices, capital investments and infrastructure. The 'normal' and climate change branches appear to be disconnected not because the solutions for climate change risks are radical, but because climate change's perceived novelty prompts each farmer to seek responses that they had not previously considered in managing risks from weather and climate variability.

Though farmers are often thought to mainstream climate change risks intuitively, this seems not to be the case for this group of farmers who have the apparent incentive, capacity and willingness to adapt. As described in the Introduction, these farmers are broadly representative of commercial farmers in South Africa, and closely resemble commercial grain farmers in higher-income countries (*e.g.*, the United States, Canada, Europe, Australia) in both farming practices and adaptive capacity. However, they have greater incentive to proactively address climate risks because of the absence of government subsidies and the scarcity of crop insurance. They consequently have more belief in climate change and are more concerned about its impacts. And they express greater desire to adapt than commercial farmers in those same higher-income countries (Prokopy et al., 2015). As a group, these farmers thus appear more likely than most others to adapt proactively. Given this, the apparent misalignment between their mental models of 'normal' and climate change risks therefore bodes ill for proactive adaptation by other groups who may be more buffered (*e.g.*, because they have better access to irrigation (Eakin et al., 2016)) or who may have lower adaptive capacity (*e.g.*, smallholder farmers in most of Africa).

The indirect mental models elicitation enabled the identification of inconsistencies and competing logics, since participants were not made aware that the interviewer sought their mental model of weather and climate change risks. The extent and further implications of this cognitive isolation should perhaps be explored using more direct methods. The applicability of the mental models approach in this further investigation is constrained by the time- and resource-intensive nature of the data collection and analysis, which limits feasible sample sizes and encourages its use in relatively homogeneous groups. Extending this work to other regions or heterogeneous groups will likely require research methods (*e.g.*, surveys) that allow for larger samples and more systematic comparisons. However, survey methods as commonly applied, poorly capture *in situ* thinking. Further methodological innovation will be needed to overcome the key limitations of each approach (*e.g.*, by systematizing mental models data collection using interactive online tools and automating parts of the analysis).

These farmers need help in understanding the ways in which climate change is similar to and compatible with the myriad risks that they otherwise routinely manage. The mainstreaming of adaptation will be difficult if climate change it is perpetually framed, by experts and farmers alike, as distinct from 'normal' climate. If farmers are unable to integrate climate change with their pre-existing risk management frameworks, they are unlikely to respond to climate change risks proactively, even when they express the need to do so. Some farmers are already poorly adapted to present climate; they do not always choose to minimize weather risks when given the opportunity, because environmental risk management competes with other risks and other objectives. For climate change, foregone adaptive opportunities are likely to become more frequent. Because climate change is cognitively isolated, trade-offs between climate risk management and competing objectives will be less purposeful. The adoption of innovations that are nominally effective for climate change (*e.g.*, CA) may forego precisely those aspects needed for climate risk management. The risk communication challenge is thus larger for commercial farmers than broadly recognized in the climate change adaptation literature. Farmers must be motivated to make the long-term investments in knowledge, equipment and infrastructure needed for effective and efficient climate risk management. Rather than emphasizing the novelty of climate change risks by framing responses as "climate change adaptation," it may be more effective to expand farmers' notion of climate variability to account for the newly dynamic and uncertain nature of the climate variables with which they are already deeply familiar.

Contributions

K.M.F. designed the study, collected and analyzed the data, and wrote the paper. S.D.D., T.S. and M.K. supervised the design and analysis, and edited the manuscript.

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Conflicts of interest

None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.gloenvcha.2018.02.010.

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